Black Ven, Dorset

[SY 347 927]–[SY 363 931]

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Introduction

The Jurassic outcrop in Great Britain terminates on the south coast in Dorset, where some of the finest landslides in Britain are located. At many locations along the Dorset coast, a permeable caprock overlies an impermeable clay. The structural relationships of the Jurassic strata are such that a variety of different subjacent beds form caprock-and-aquiclude pairs, and within this range of landslide generators, each has different properties and styles of failure (Brunsden, 1996b).

Among these, Black Ven (Figure 6.33) and (Figure 6.34), located between Charmouth and Lyme Regis, is of particular interest because of its active mudslides. Indeed, it is the most active and complex landslide site in the British Isles. It comprises rotational slides, topples, rockfalls and slumps in Upper Greensand, above mudslides, muciflows and sandflows, which feed down to the beach across Liassic materials. It has a long history (Lang, 1928; Arber, 1941, 1973; Wilson *et al.,* 1958; Brunsden, 1969, 1984; Brunsden and Goudie, 1981; Chandler and Cooper, 1988, 1989; Chandler and Brunsden, 1995; Brunsden and Chandler, 1996), but its present character was established by major movements that took place in 1956–1957, 1958 (Conway, 1974) and more recently by renewed activity in the 1980s and 1990s (Figure 6.35). The cliffs reach 150 m above OD. Cliff retreat in the order of 5 m a^{-1} to 30 m a^{-1} is typical during periods of activity. Between major events, erosion at the toe is around 15 m a^{-1} to 40 m a^{-1}. During periods when detached material at the head of the slope is highly saturated, debris tumbles off the edge of an upper bench and drops 20 m onto the middle of three terraces. The upper segment of the Black Ven slope is therefore loaded at the head of each bench. The change begins at the rear scar, where the cycle of primary instability is generated. The original road along the coast was destroyed by landslips in the 18th century (Koh, 1990). A cart track running parallel to the road 100 m farther inland disappeared in 1965 and a section of the Heritage Coast Path collapsed in 1985; it was renewed, but lost again in 1994.

By the time the moving material has reached the middle terrace, mudslides and mudflows have developed. The debris is funnelled into large mudslide tracks, which pour across the cliff separating the middle and lower terraces. The process repeats as the material moves across the top of the Blue Lias towards the beach where the mudslides merge to form large composite fans and toe lobes.

Description

The Black Ven cliff is composed of the Blue Lias, Shales-with-Beef, Black Ven Marls and Belemnite Marl divisions of the Lower Lias (Lower Jurassic), overlain unconformably by Gault Clay and then by the Foxmould and Chert Beds divisions of the Upper Greensand (Lower Cretaceous) (Figure 6.36).

Dips in the Jurassic beds are about 2°–3° south-east or ESE, and the plane of uncon-formity at the base of the Cretaceous strata clips 1°–2° south or SSW. The cliff profile (Figure 6.37) shows well-developed terraces at the levels of the base of the Black Ven Marls (Conway, 1974). These terraces or benches are caused by the presence of resistant horizons within the Lower Lias. A fourth resistant horizon gives rise to a less well-developed terrace feature at the top of the Blue Lias, but this is often obscured by landslip deposits. A number of minor terraces are developed above the other resistant horizons, but they are not very extensive horizontally.

In the Upper Greensand, brecciated Chert Beds consist of broken chert in a firm, coarse sandy clay matrix with some iron and manganese oxide concentration in the lower part. The beds are much harder than the underlying decalcified Foxmould sands and this has resulted in the development of a steep upper cliff, the height of which is sufficient to allow the generation of shear stresses far in excess of the resistance offered by the decalcified sands. This results in the propagation of single- and multiple-failure rotational slides that affect the full thickness of the Upper Greensand. Secondary iron oxides have been deposited at the base of the Chert Beds, impeding the downward movement of groundwater. This results in springs being thrown out at the cliff-face, which have cut deep gullies in the cliffs of Foxmould sand below. This process is greatly assisted by land drainage from the top of the cliffs. Many of the initial movements of slide blocks occur as a result of failure of the conical buttresses that develop between these gullies.

The base level to which the gullying and the rotational slides operate could be the top of the Gault Clay, the level of the highest terrace. Large accumulations of sand and chert debris build up on this terrace, and during the winter months are rapidly saturated. The water is discharged on the cliff-face at the junction of the debris with the Gault Clay. This results in extensive seepage erosion (Conway, 1974) and gullying, leading to failure, and the debris is carried down the gullies onto the next terrace below. The upper cliff sides are thus deprived of part of their toe areas and stress is again able to build up to the level required to regenerate the cycle of primary instability.

Although gullied by seepage erosion the major cause of the removal of material from the Belemnite Marl cliffs are joint-controlled rockfall caused by erosional unloading, and frost action. The material received by the second terrace, at the base of the Belemnite Marl cliffs, is again rapidly saturated in winter and loaded at its head by the cascade of mud from the terrace above. It discharges water and sediment onto the next cliff-face from its lower boundary. The Black Ven Marls below is soft and fissured. Subjected to seepage erosion, it is rapidly gullied and small rotational failures occur. Water-charged debris, carried down gullies or pushed over the terrace edge by material accumulating behind, strips off the outer, weathered, layer of clay. Removal of this material from the terrace face results in steepening of the cliff and allows the generation of higher stresses in the clay, which in consequence approaches a failure condition. The clay, which is heavily over-consolidated, takes in water, swelling and weakening until failure takes place. On the benches major mudflows, mudslides and sheet-flows descend to the third and fourth terraces at the base of the Black Ven Marls.

The process is repeated from the fourth terrace over the soft Shales-with-Beef cliff down to the beach. Flows and slides coalesce to form large composite toe fans, which often (as in some recent years) completely envelop the fifth and lowest terrace, at the top of the Blue Lias, and much of the beach. This terrace is really a toe fan, a composite body formed by the accumulation of debris from many cycles of secondary instability, and built on an original which resulted from a single catastrophic event in 1958 (Lang, 1959). The upslope part of the fan, lying on the engulfed fifth terrace, displays transverse pressure ridges, while the downslope part shows extensive tension cracking and isolated pressure structures. Extensive sand-runs resulting from periodic flash-floods fill in and cover the irregular surface of the clay toe fan. At times of little or no mudslide activity the fine-grained material in the toe lobes is washed away to leave boulder arcs on the beach.

The above description is based on Arber (1941, 1973), Conway (1974), Brunsden and Allison (1990) and Koh (1990). More recent and much more detailed investigation has been made possible by the development of an archival, three-dimensional photogrammetric technique that is able to derive quantitative spatial information of known accuracy, from historical aerial photographs (Chandler and Cooper, 1988). The technique was itself developed using Black Ven as testbed and exemplar (Chandler and Cooper, 1988, 1989). These authors show how analytical photogrammetry can be applied to historical photographs, a hitherto untapped source of data for geomor-phologists and other Earth scientists. They term their research the 'archival photo-grammetric technique'. They point out that, lacking camera calibration data and co-ordinated ground control points, conventional photogrammetry is impossible. To monitor the development of a feature a sequence of photographs is needed. The archival photogrammetric technique is based around computerized analytical techniques, mainly a *self calibrating bundle adjustment.* This establishes, digitally, the relationship between the photographs and a ground co-ordinate system. The replacement of the analogue stereoplotter with a digital mathematical model of this type is a well-established technique (Ghosh, 1979). The process involves photo acquisition, identification and derivation of control points, photo measurement, photogrammetric processing, data extraction, data processing/presentation, and interpretation.

This methodology was validated using Black Ven, selected because, being so active, it has shown marked changes. As pointed out by Chandler and Brunsden (1995), the site has been subject to several aerial photograph surveys constituting the 1946, 1958, 1969, 1976 and 1988 aerial photographic 'epochs' (see (Figure 6.38), (Figure 6.39), (Figure 6.40), (Figure 6.41), (Figure 6.42). A further epoch, for 1995, is analysed by Brunsden and Chandler (1996).

The basic data units used for all photogrammetrically based methods are the three-dimensional co-ordinates that can be obtained with a density and efficiency which is unobtainable by other techniques. Data extraction is greater, denser and with subsequent data processing, more powerful and flexible. The co-ordinate data can be used to provide basic planimetry, slope profiles and contours (Chandler *et al.,* 1987) (see (Figure 6.43)), digital terrain models (DTMs) (shown as isometric views in (Figure 6.44)) and movement vectors. The technique can be regarded as an updating of previous methods of geomorphological mapping. As remarked by Chandler and Cooper (1988), precise definition and coding of morphological boundaries by rigorous photogrammetric techniques combines the benefits of geomorphological interpretation with positional relevance. Visual comparison between photographs at two widely differing times provides a basic tool which can be used to identify, quantify and interpret areas that display any degree of change.

Although contour plans provide a full description of site morphology at the different epochs it is difficult to identify areas of change by visual inspection. However, subtracting a grid surface produced at one epoch from the grid of a later or earlier epoch creates a grid surface that represents the change of form over the period defined by the photographs. This surface can be contoured, thus quantifying the spatial effects of processes: some areas will have lost material, others will have gained material, and some will have exhibited no change. Chandler and Cooper (1988) caution that the last-mentioned set of areas are not necessarily inactive areas. They can be areas where the input of material has equalled output over the defined period (see (Figure 6.45)a–f).

Chandler and Brunsden (1995) deal in more detail with the problems of applying photogrammetric methods to archive photographs, in particular the components of the self-calibrating bundle adjustment. At Black Ven the control points used at all epochs are derived from one Ordnance Survey plan, which therefore acts as a datum.

Koh (1990) set up an automated data-gathering system recording rainfall, porewater pressure, loading, surface movement and subsurface displacement, below the Belemnite Marl cliffs at Black Ven. His results are summarized in (Figure 6.46) where the response of porewater pressure and cumulative displacement to monthly rainfall is very apparent. Koh suggests two alternative mechanisms: visco-plastic flow as described by the Bingham equation, and the release of dissolved solids, according to the groundwater chemistry shear-strength model of Moore (1988).

Interpretation

(a) 'The reservoir principle'

It has been suggested by Denness (1972) and Conway (1974) that the sequential process active at Black Ven may best be understood in terms of the presence, in intimate association with the instability, of bodies of material that behave as reservoirs of groundwater with effectively impermeable floors. Naturally occurring groundwater reservoirs may be seen as consisting of two kinds, primary and secondary, depending on whether the reservoir material itself is an in-situ rock body or an accumulation of rock debris resulting from slope degradation. Hence, the in-situ Upper Greensand is the primary reservoir at Black Ven. The debris accumulations on the terraces below are secondary reservoirs, and it is the gradual release of accumulated water from these that leads to the unusually rapid degradation of the material on the terraces and the rapid transport of their material to the cliff-foot.

(b) The episodic landform change model of Chandler and Brunsden (1995)

Chandler and Brunsden (1995) include a 'Speculative Discussion' based on results from the archival photogrammetric technique. One view of morphological change is that landform change takes place when a state of process equilibrium and morphological stability is perturbed by an impulse of change of sufficient character to overcome the tolerance Of the system (Brunsden and Thornes, 1979; Brunsden, 1985, 1990). This overcoming of tolerance may be divided into two phases: 'preparatory' impulses, which predispose a system to change, and 'triggering' impulses, which actually push the system over a threshold. In the case of Black Ven there is evidence that the system was prepared for a new phase of mudsliding by the erosion and steepening of the cliffs to a new average angle exceeding 19°. The 1958–1959 mudslides failed at about 19°, which can be regarded as a failure threshold. However, this is in part an artefact of the fact that data for 1958 are available. The 1958 data therefore represent the first epoch, which happens to have been soon after failure, rather than failure activity at the threshold angle itself.

Following this initial rapid movement, the cliffs adjusted by building lobes of mud into the sea, and in the ensuing ten years the erosional wave diffused upslope to form low-angle slopes on the upper benches. In doing so, the form was maintained even though the whole complex moved inland by as much as 90 m. There was a change in the proportion of low-angle slopes between 1969 and 1988 because the accumulation lobes were being removed by the sea, but the degradation slopes maintained their form. The main processes involved were the cascades of material over the terraces, the parallel retreat of the undercliffs and the rapid transport of material away from the foot of the cliffs and across the benches by the mudslides. Chandler and Brunsden (1995) observe that this is a good example of a retreating but unchanging slope form being maintained by an efficient basal removal condition. Some impression of the rate of recession may be obtained from (Figure 6.47).

The data suggest that following an impulse of change, the Black Ven system adjusts dynamically and develops a new characteristic form. There is a rapid transmission of energy and material through the system and a remarkable interdependence of the slope-process components. The retreat of the cliffs and the total basal removal of each bench demonstrates almost perfect component coupling. Over a 30-year period the system fulfils most of the requirements of a system in steady state.

This opinion is supported by the extraordinary record of the DTMs of elevation difference between 1958 and 1988. These show that over 200 000 m^3 of sediment was transported from the cliff-top to the sea through one of the mudslide systems and yet the overall cliff form remained unchanged to a large extent.

The data may also be used to inform discussion of the timescales of landform change. By manipulating the mean slope-angles at all epochs in a Computer Assisted Design (CAD) system it is possible to produce projections of the mean slope-angle into the future. This can be used to set up a working hypothesis of the possible time adjustments required. The impulse of change or threshold activity crossing is followed by a rapid reduction of slope angles as the mudslides form and the seaward lobes accumulate. This was probably achieved early in the 1960s but the epoch interval (1958–1969) only permits a resolution of the reaction time to 11 years.

The system then relaxed over a further period of 7 years. Therefore, this model suggests that it takes about 20 years to achieve the current form, which by 1995 had been maintained for 16 years. The data suggest that during this period the elevations changed very little, that input was close to output, and that, overall, the erosion volumes were diminishing. Nevertheless, the mean slope-angle, based on 11 000 points shows a change from 17.7° to 18.1°. If this is significant it suggests that the characteristic form is a dynamic one of change at a constant rate. This would allow a linear projection and a prediction of the next major dynamic phase in about 2016 AD, a frequency of about 60 years. This may then be used as a basis of an episodic landform change model (Figure 6.48) based on the marine erosion rate that prepares the system by steepening the slope angle.

However, Chandler and Brunsden (1995) point out that this linear model is almost certainly incorrect. The 1969, 1976 and 1988 data points probably suggest an exponential decay towards the threshold activity angle. In this case, the characteristic form has not yet been achieved, the relaxation time is in progress and a long period of slow slope degradation can be expected. The length of time before the next active phase will then be determined by the rate at which the accumulation lobe, plus any input from upslope, is removed and the cliffs steepened towards the threshold. Chandler and Brunsden (1995) remark that because of the unknown input to the lobes during this basal removal phase, this will no doubt prove to be an example of complex response.

(c) The episodic landform change model of Brunsden and Chandler (1996)

A year later, Brunsden and Chandler (1996) substantially revised the 1995 episodic landform change model, partly in response to a dramatic sequence of events that took place on 7 August 1994 at 7.35 in the evening. A large-scale, rare event took place at the western system of mudslides. The previous winter had been one of the wettest on record, with movement observed throughout the cascades. In particular, the dormant systems to the west developed large cracks at their head and very wet failures all along the top of the Belemnite Marl slope. Black Ven (west) began to develop three distinct feeder tracks on its western margin. In February a non-circular slide with a deep graben developed at the toe, and mudslides were re-activated on all terraces. The Spittles mudslide continued to extend in a headward direction with a graben developing along-side the abandoned Roman Road, where the road itself was split wide open.

During January and February 1994 at Black Ven (west), a tension crack 100 m long opened up across the edge of Lyme Regis golf course about 5 m from the cliff edge. The detached piece then settled very slowly so that, by the end of the winter, it had come to rest about 10 m down the cliff-face. A dry summer followed, but surprisingly in August the detached piece rapidly descended the cliff and suddenly loaded the accumulated debris on the uppermost bench, above the Belemnite Marl.

This debris, consisting of dry sand and gravel, was pushed forward between 40 m and 50 m so that approximately 60 000 m^3 of dry, fine-grained sand descended the vertical clay cliff. This mass appears to have fluidized (the exact mechanism is not known) because the material flowed in a few minutes, in a sheet form, to within 20 m of the sea. The flow track below the clay cliff descended 323 m horizontally and 90 m vertically. The dimensions of this landslide were: width 100–120 m, length 525 m, with a flow track of 0.3–1.0 m deep and an average angle of 13°. The deposit came to rest as a thin sheet of fine-grained sand with some mixture of clays. The deposit was laminated, had a clean margin to the mudslide surface below, with very sharp edges, shallow levees in places and a very abrupt termination of the frontal lobe. The surface was streamlined, boulders and gravel from the chert beds were strung out in lines and the overall surface was powdery.

Very shortly after the event all of the mudslides moved forwards, undoubtedly because of the rapid undrained loading of the terraces. On the edge of the Belemnite Marl cliff the loss of the toe of the upper terrace landslides caused a major rotational slide to develop, forming a very prominent scar in the undercliff.

The early autumn of 1994 occasioned significant rainfall. The loose sand, varying in depth between 0.3 m and 1.0 m, quickly became saturated and the surface was transformed into an inaccessible metastable sand. During the very wet winter of 1995 this landslide surface began to sort itself into distinct mud streams with pressure ridges and wet fans spread across the accumulation lobe. Unusually, a deep gully developed over the whole length of the track, which became a fully integrated stream system by the spring. Overall the event pushed a lobe of mud 10 m into the sea.

This event is one of the first dry sand-runs to have been observed. Brunsden and Chandler (1996) could find no other accounts in the literature. Certainly such events are unknown either on Black Ven or in West Dorset. It is known that the event occurred over a very short timescale because there were witnesses who could give approximate timings.

The effect of big event on the gross morphology was to flatten the whole landslide by blanketing everything in a thin layer of sand in just a few minutes. This reduced the average slope-angle by 2°, to 13°, and so delayed the return of the system, by undercutting and slope steepening, to a new unstable state.

As stated, this spectacular event contributed to the development of a revised episodic land-form change model (Brunsden and Chandler, 1996). Other contributory factors were: further development of automated digital photogrammetry; new DTM software capabilities; an additional epoch of aerial photographs and derived spatial data, 1995; and new observations of mudslide activity in the period 1988–1995.

As pointed out by Brunsden and Chandler (1996), the episodic landform change model developed by Chandler and Brunsden (1995) could only be speculative, as it involved certain simplifications. For example, most of the functions available in the DTM processing package then available could only operate with a rectangular grid-based DTM. The consequent rectangular and imprecisely specified boundaries to the system resulted in probable distortion to the slope-angle histograms and the mean slope-angles derived from them. Inaccurate specification of boundaries also prevented separate processing and examination of what are in fact two independent mudslide systems. Also, the model was based exclusively on basal erosion; slope steepness triggering of mass-movement activity and other important controlling variables were omitted.

The 1995 epoch shows that the eastern mudslide remained effectively unchanged in form between 1988 and 1995, although very high rainfall in 1994 and 1995 caused some movement and tension cracking on the uppermost bench and slipping of some toe material over the cliff edge of the Belemnite Marl. The debris built up at the base of the cliffs and it must be assumed that the terraced mudslides have been loaded at their heads. Some gentle forward movement produced small slides in the main track, with lobes spread across the terraces, but the overall increase of slope angle from 18.1° to 19.6° must be destabilizing the system (Figure 6.49).

The western landslide continued to show erosion at the head, but with increasing evidence that the system was discharging sediment in a steady-state manner similar to the previous 20 years. There was no change in the morphology and storage of the track.

The most important discovery from Brunsden and Chandler's new (1996) analysis was that during the relatively drier and less-dynamic years of the mid-1970s the mudslides did not carry away all of the debris supplied at the back of the terraces that accumulated as medium-angle debris slopes. In consequence the slope-angle distributions began to move towards the 1946 bi-modal pattern and a higher mean value (Figure 6.49). The onset of years of greater rainfall in the 1980s reversed this trend to reveal the true nature of the relaxation variability

Brunsden and Chandler (1996) were also able to make a more detailed analysis of climatic influences. Monitored data are not available for Black Ven; however, recent research on the occurrence of landslides and climatic change on the south coast of Britain (Brunsden and Ibsen, 1994a–c; Brunsden *et al.,* 1995; Ibsen and Brunsden, 1996) has provided data on landslide occurrence at a similar temporal scale to the Black Ven photographic evidence (Figure 6.50). This facilitates understanding of the cumulative data recorded on the photographs and enables refinements to the episodic landform change model to be made.

A recent investigation for the European EPOCH programme (Brunsden and Ibsen, 1994a–c) has shown that the European historical archive of landslide data, though incomplete, is very rich. It has been used to create a database (Brunsden *et al.,* 1995) on the occurrence of landslides on the south coast of England. It was found possible to derive a time-series that could be related to the broad diurnal series provided by such stations as Ventnor, Portland and Lyme Regis. The series for West Dorset displays a pattern similar to that for the south coast as a whole, and for Ventnor. The latter, which is a long, complete and homogeneous record, is used to determine the climatic landslide control for the south coast (Figure 6.50). Three points are helpful in the development of the episodic landform change model.

1. The Pleistocene history of Black Ven is not known, but the plateau top, the valley-side slopes to the Lym and Char rivers, the slopes of the neighbouring landslides at Stonebarrow and Golden Cap and the westernmost areas of the Black Ven complex are mantled with head up to 3 m thick. Late Pleistocene mudslides are known to underlie some of Charmouth and the lower valley-side slopes of the River Char. These can be up to 20 m deep (Brunsden and Jones, 1976). The Spittles area on the western side of Black Ven is a re-activation, in 1986, of a relict, very degraded landslide slope, which is mantled in solifluction debris and suggests that post-glacial erosion by the sea only reached the old system in historic times. The database has no records for the coast until 5500–3000 BP when it is thought that the rising sea first renewed its attack on the degraded, head-covered, pre-glacial cliffs.
2. The first records for Lyme Regis and the Axmouth to Lyme Regis Undercliffs Nature Reserve (specifically, Haven Cliffs) are from the 11th century, but details are scanty. There are more substantial records for the period of the Little Ice Age, with 13 records from West Dorset and the National Nature Reserve between 1592 and 1843, and a heavy concentration in the 16th and 17th centuries. The records are all historical narrative reports. The central, dormant, but only partly degraded, landslide of Black Ven may well date from this period since the oldest trees on the site are about 200 years old. However, these records need not relate to a period of greater rainfall. Their fortuitous recording may indicate movements due to marine erosion or weathering.
3. Records are far fuller for the modern period (the last 200 years), with annual and decadal data showing an apparent increase of events in the last century, and a sequence of troughs and peaks.

The obvious change in the nature and intensity of reporting leads to uncertainty as to whether all the changes shown are due to natural causes (Brunsden *et al.,* 1995). On the coast it is logical to ascribe some of the increase to sea-level rise and erosion of the sea cliffs. There appears to be an apparent concentration and periodicity, shortening towards the present-day, in the number of landslides this century (Ibsen, 1994). The periodicity that is most significant in that central and southern England has experienced a cyclical pattern in which the wet years gave rise to greater geomorphological activity. There is a concentration of landsliding during the periods 1912–1913, 1922–1932, 1936–1941, 1950–1970, 1975–1982 and 1993–1995. This is a frequency of 5–10 years, with the episodes of sediment transfer lasting several years. Wet-year sequences with three or more wet years in succession occurred during 1877–1882, 1913–1915, 1922–1932, 1936–1939, 1952–1954, 1963–1970 and 1978–1982, all coinciding with landslide records. The precipitation record for the Axmouth to Lyme Regis Undercliffs National Nature Reserve broadly supports this pattern.

It therefore seems reasonable to accept, for the modelling of the episodic behaviour of the West Dorset landslides, a 'wet' year climatic control of 5–10 years lasting for 3–6 years which is superimposed on the trend for increasing wetness, sea-level rise, and slope steepening over the last 60 years.

These records allow a further speculative model for episodic landform change at Black Ven to be developed (Brunsden and Chandler, 1996) (Figure 6.51), replacing that given by Chandler and Brunsden (1995). During the last glacial period the whole coastal slope was abandoned by the sea so that erosion was curtailed. The slope evolved under periglacial conditions, with solifluction and major landslides. During the post-glacial period the landslide scars and the structural benches degraded and became vegetated. After 5500 BP the rising sea began to remove the solifluction apron and eroded the abandoned pre-glacial sea cliffs. In the Black Ven complex, the uppermost slopes of the Spittles are still in a periglacial form perhaps because the toe is protected by a sea wall. The Spittles landslide itself was in a similar state until it became so undercut that it failed in 1986.

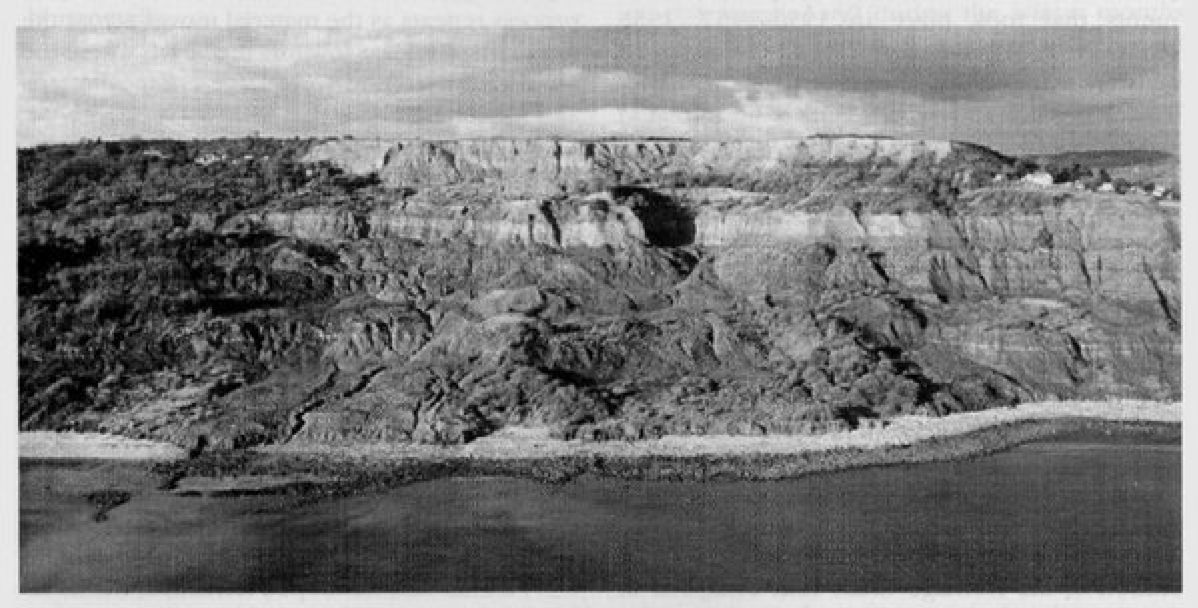
The morphology of Lyme Bay and the distribution of wave energy ensured that the cliffs to the east became unstable at an earlier date. The central part is now in a metastable, vegetated state and appears to have been through a phase of activity about 200 years ago. There are no solifluction deposits surviving on this slope except for the cappings on slump blocks from the backscar. The slides then degraded to an overall slope-angle of about 17°, with a bi-modal distribution of slope angles reflecting the vegetation of the rear scarp, the growth of talus and debris slopes at the base of the steep slopes, and the smoothing of the structural slopes. This state continued until 1994–1995 when movement began on all of the terraces in response to continued undercutting and the wettest year on record. Almost certainly, Black Ven (west and east) reacted in the same way, with re-activation rather earlier than 1957–1958, but no evidence survives (Brunsden and Chandler, 1996). Present understanding of the spatial relationships of its various parts is shown in the geomorphological map of Brunsden and Chandler (1996) (Figure 6.52).

Conclusions

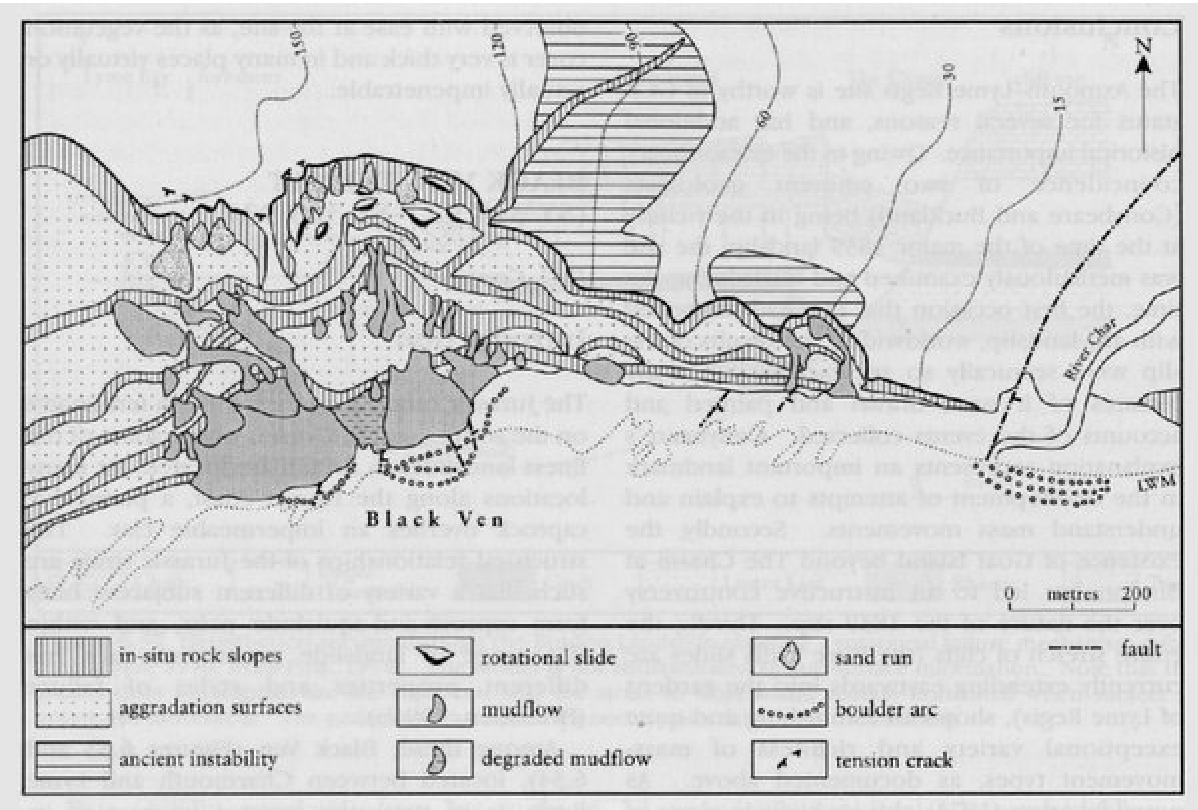
Black Ven has a long history of landslide activity; but major movements have been episodic. It is remarkable for the detail in which it has been studied, and the extent to which its mechanisms are understood, ranging from the notion that aquifers can act as reservoirs, the gradual release of groundwater from which has kept the downslope transport of materials at Black Ven in motion as far as the sea itself, to the sophisticated landform change models of Chandler and Brunsden (1995) and Brunsden and Chandler (1996). The rapid replacement, a year later and by the same authors, of the earlier of these two models is unusual but amply justified by the list of 'developments since 1989' given by Brunsden and Chandler (1996) in presenting the later model.

The sheer scale of current and recent activity on the Black Ven slope, and the close attention that has been accorded to it, strongly justify its inclusion as a Geological Conservation Review site.

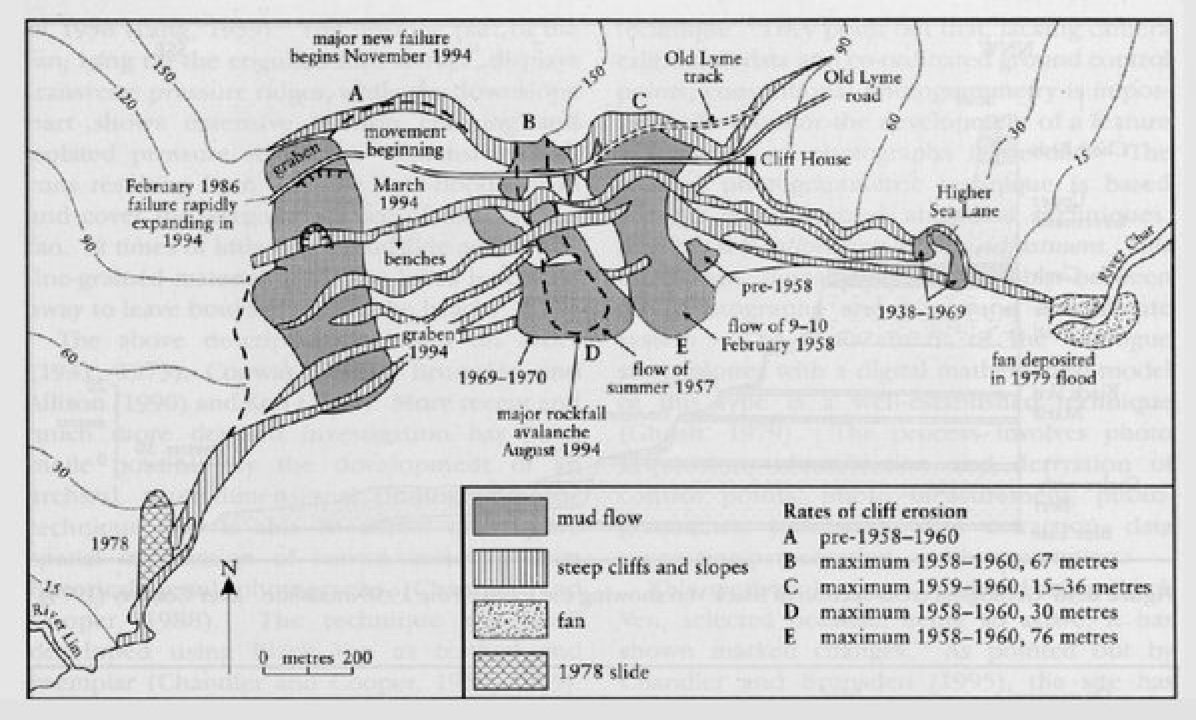
References



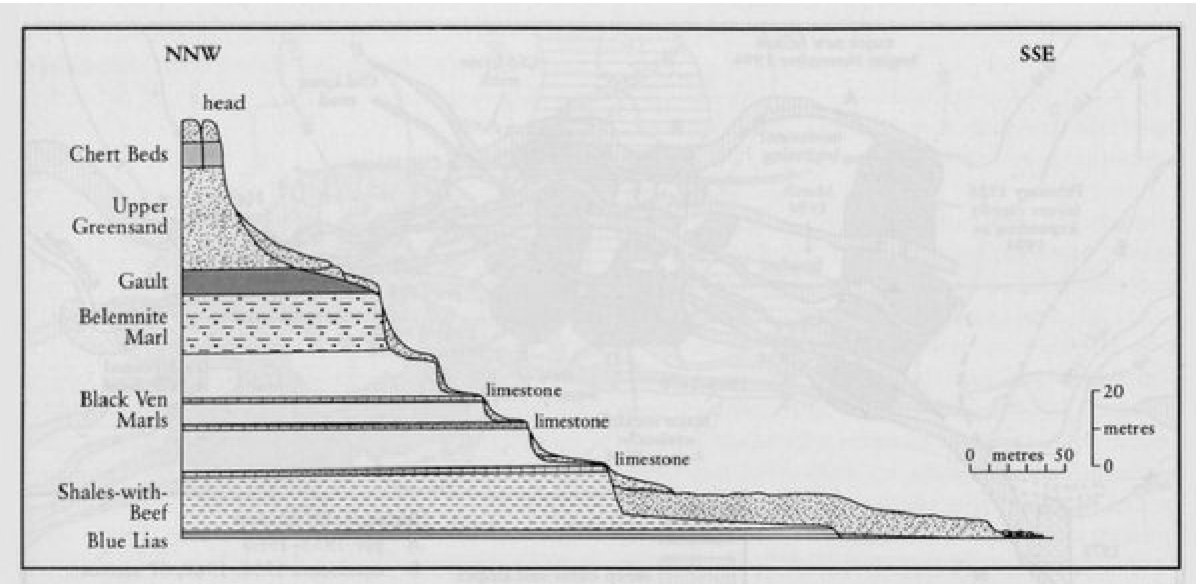
(Figure 6.33) The Black Ven landslide. (Photo: R. Edmonds, Dorset County Council.)



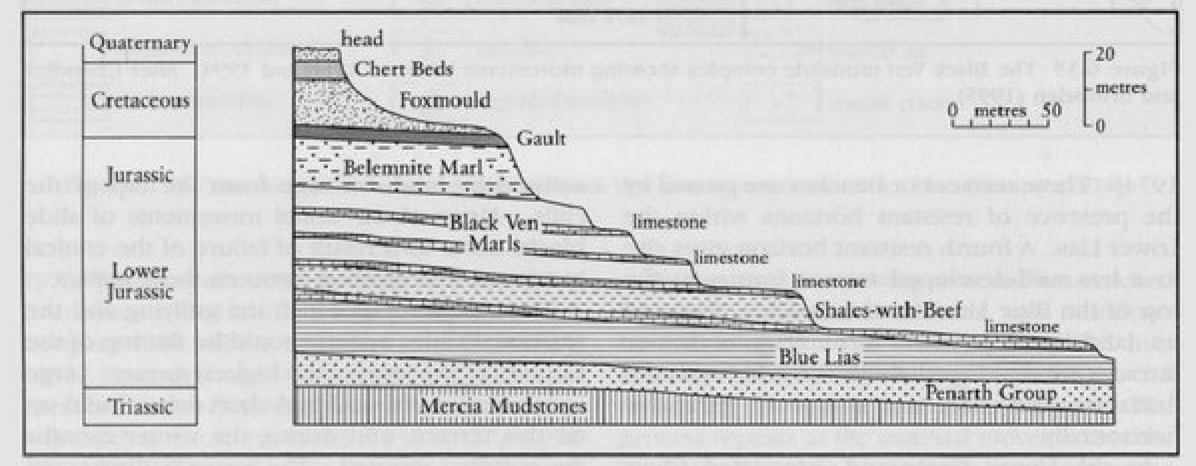
(Figure 6.34) The mass-movement complex at Black Ven as it appeared in 1974. After Conway (1974).



(Figure 6.35) The Black Ven mudslide complex showing movements between 1958 and 1994. After Chandler and Brunsden (1995).



(Figure 6.36) Geological cross-section of Black Ven showing the lobes of the 1958 mudslide. After Conway (1974).



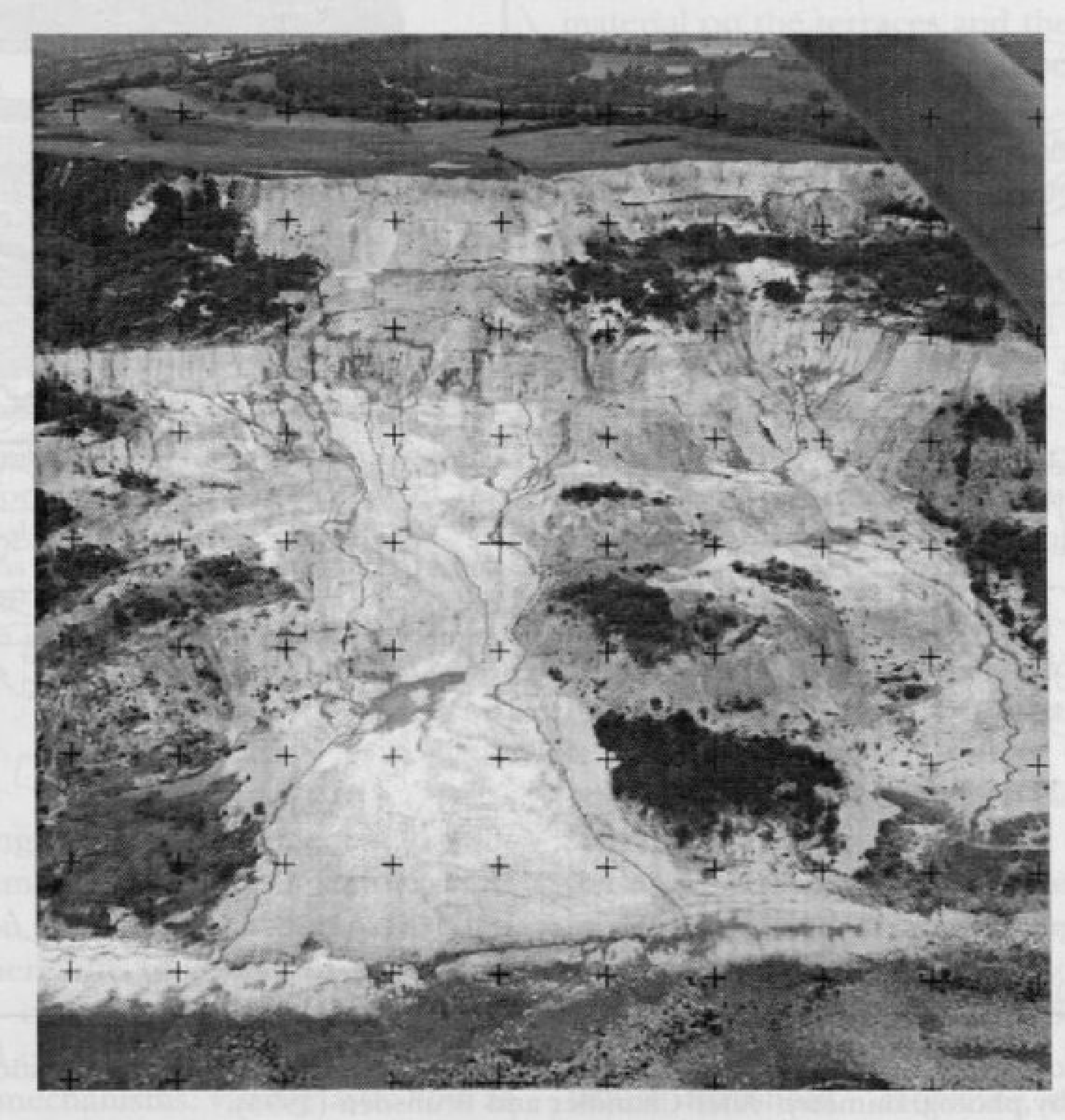
(Figure 6.37) Section through cliffs to the west of Black Ven showing regional dip and benches under-scoured by landslide debris.

(Figure 6.38) Aerial photograph for the 1946 epoch. (Photo: English Heritage (NMR) RAF Photography.)

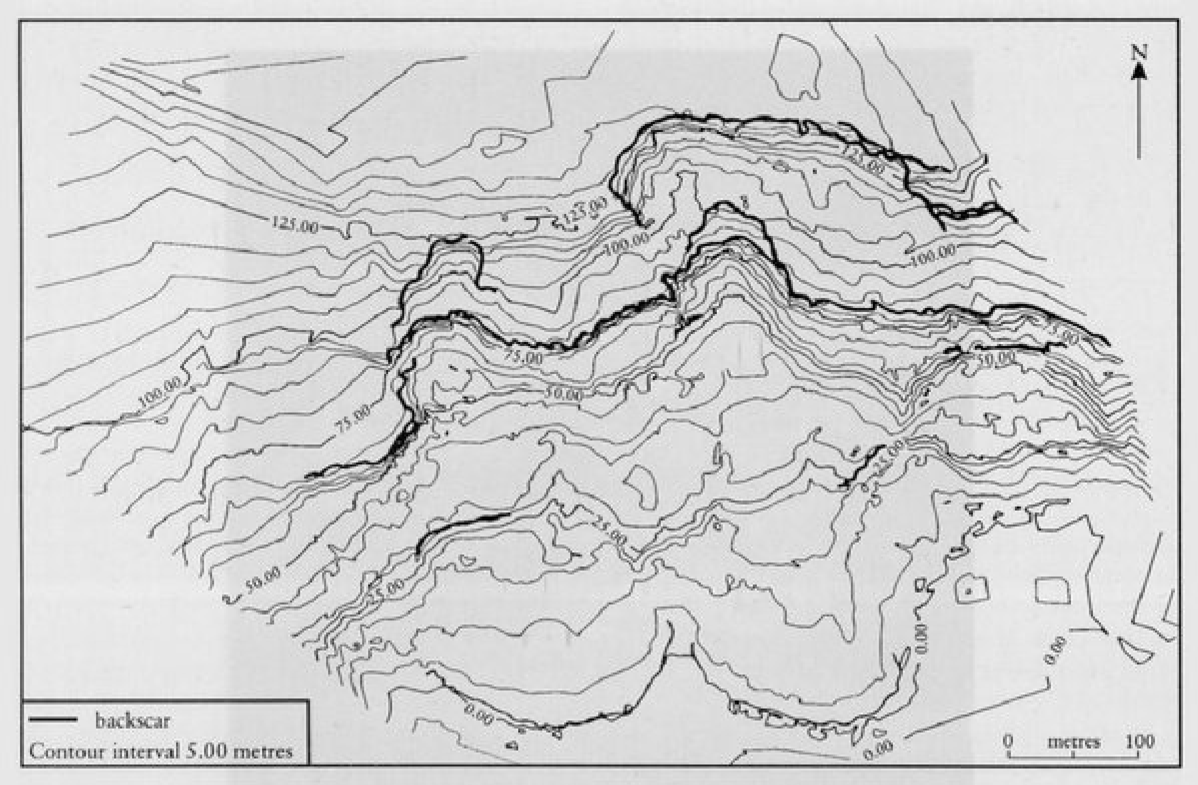
(Figure 6.39) Oblique aerial photograph for the 1958 epoch. (Photo: Crown Copyright/MOD. Reproduced with the permission of the Controller of Her Majesty's Stationery Office.)

(Figure 6.40) Aerial photograph for the 1969 epoch. (Photo: Copyright reserved Cambridge University Collection of Air Photographs.)

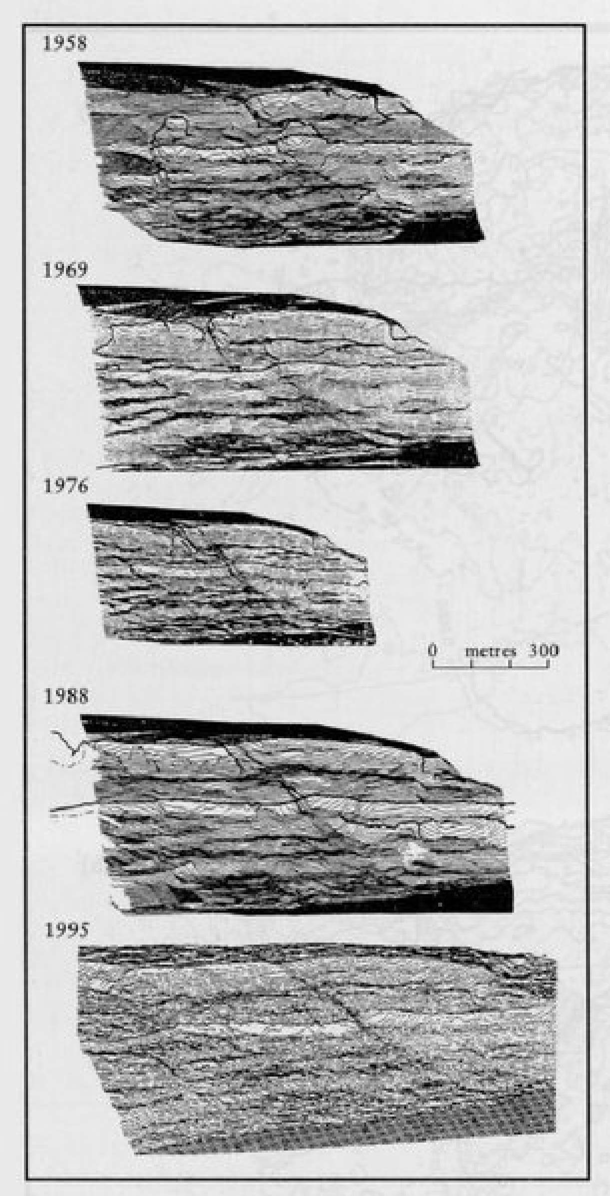
(Figure 6.41) Aerial photograph for the 1976 epoch. (Photo: reproduced by permission of Ordnance Survey on behalf of HMSO Crown Copyright (2006). All rights reserved. Ordnance Survey Licence number 100038718.)



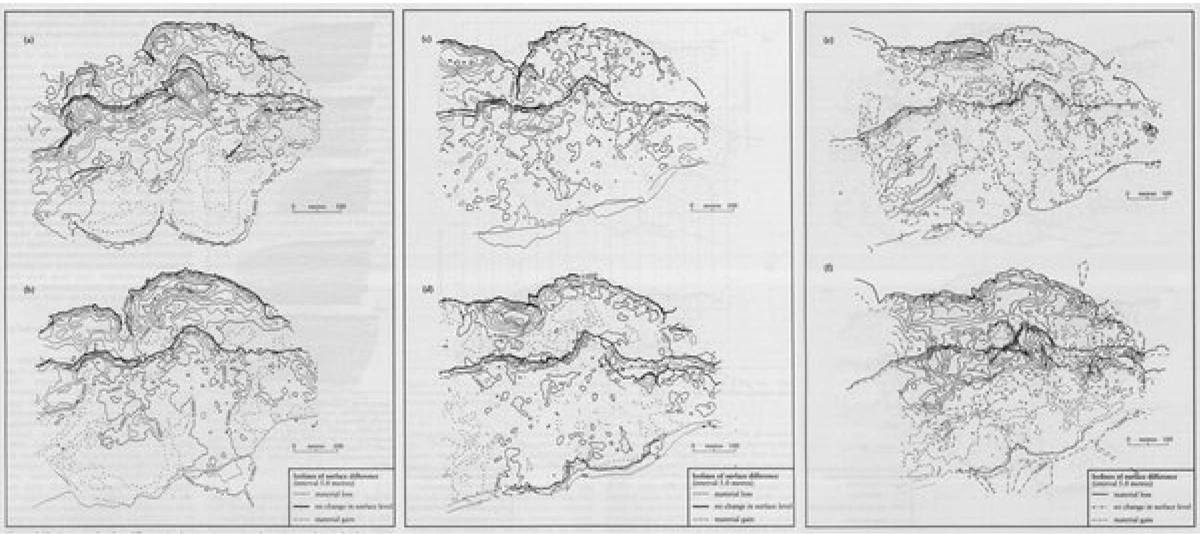
(Figure 6.42) Oblique aerial photograph for the 1988 epoch. (Photo: J. Chandler.)



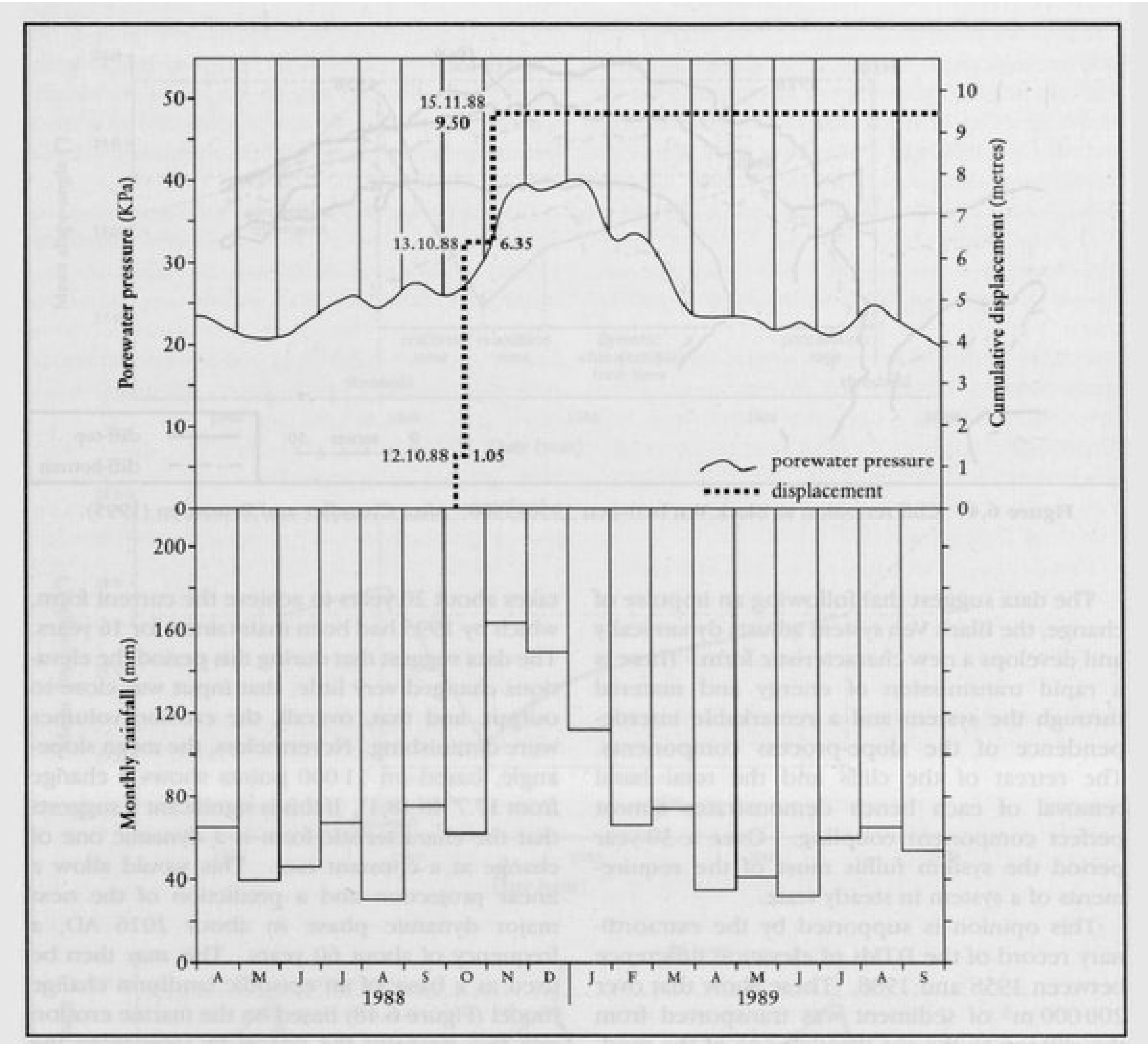
(Figure 6.43) Contour plot of Black yen after the 1958 movements produced by interpolation of 11 000 data points established by photogrammetry. After Chandler and Brunsden (1995).



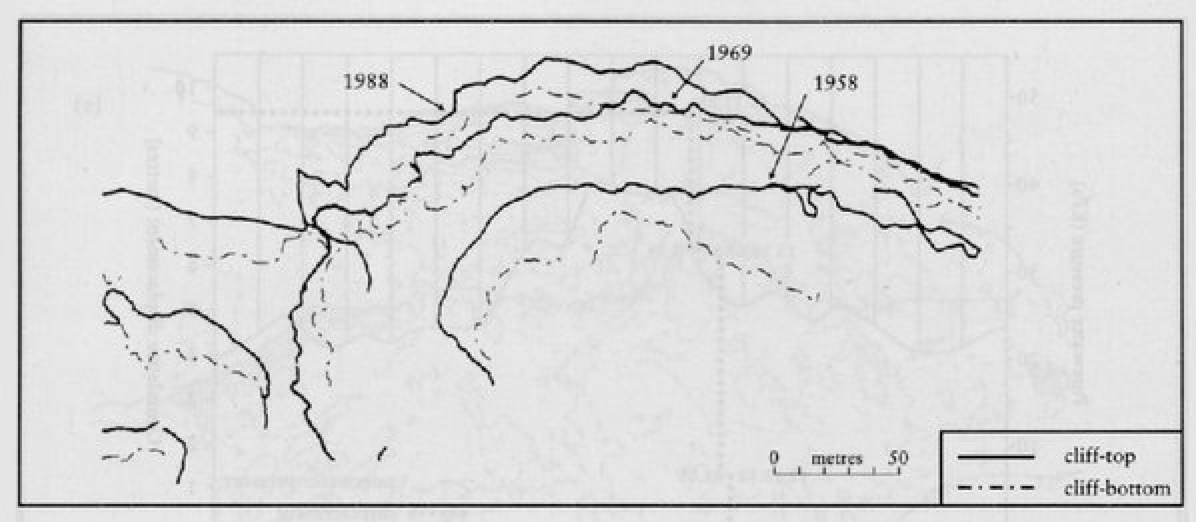
(Figure 6.44) Digital terrain models (DTMs) shown as isometric views for the Black Ven mudslide at five epochs between 1958 and 1995. Note that the 1958–1988 epochs are based on analytical photogrammetry and an 11000 point data set. The 1995 model is based on a larger data set aquired by digital photogrammetry. After Chandler and Brunsden (1995).



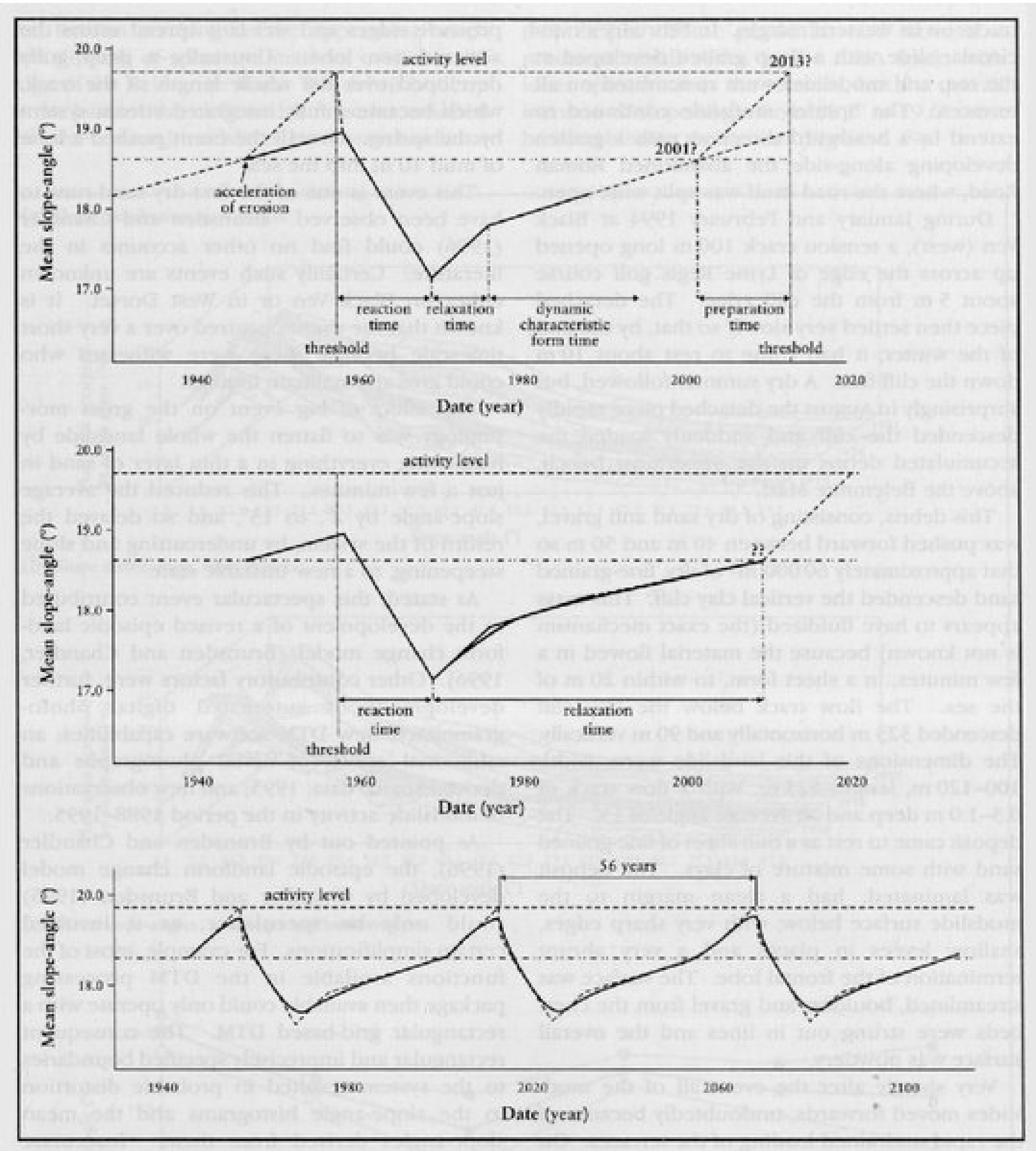
(Figure 6.45) Contours of surface difference in elevation (i.e. erosion-deposition-no change) for the periods (a) 1958–1946, and (b) 1969–1958. Period (a) shows the location of the 1958 failures. This can be regarded as the formative event. Period (b) shows the diffusion of the wave erosion of the toe and continued input. The 'no change' along the main mudslide axis shows input = output and dynamic equilibrium over a decade interval. After Chandler and Brunsden (1995). Contours of surface difference in elevation (i.e. erosion-deposition-no change) for the periods (c) 1976–1969, and (d) 1988–1976. The 'no change' along the main mudslide axis shows input = output and dynamic equilibrium over a decade interval. After Chandler and Brunsden (1995). continued. Contours of surface difference in elevation (i.e. erosion–deposition–no change) for the periods (e) 1995–1988, and (1) 1988–1946. The 'no change' along the main mudslide axis shows input = output and dynamic equilibrium over a decade interval. After Brunsden and Chandler (1996).



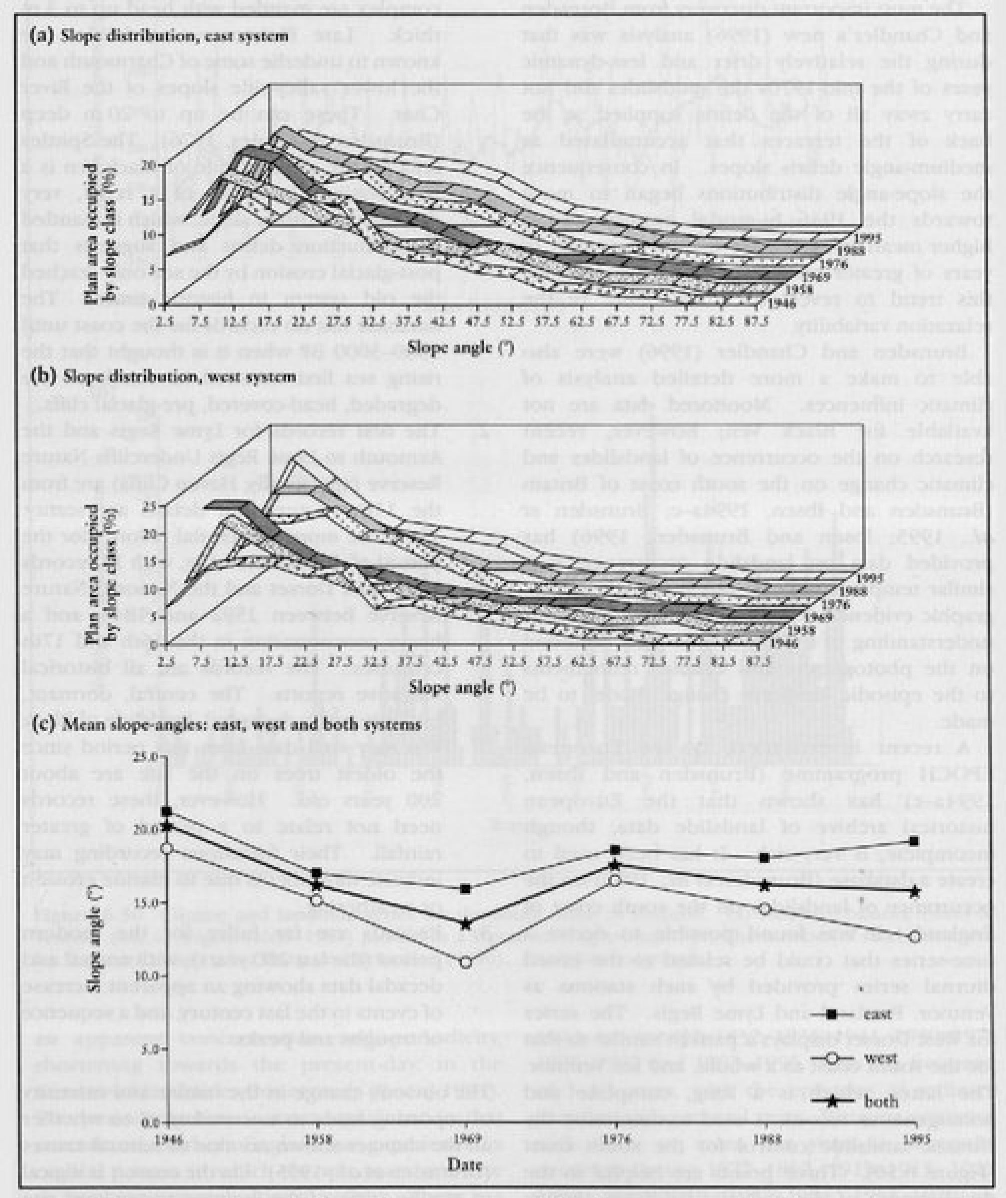
(Figure 6.46) The seasonal behaviour of rainfall movement and porewater pressure at Black Ven. The observation that movement ceased on 5/11/88 suggests that there may have been a considerable strength gain following movement. After Koh (1990).



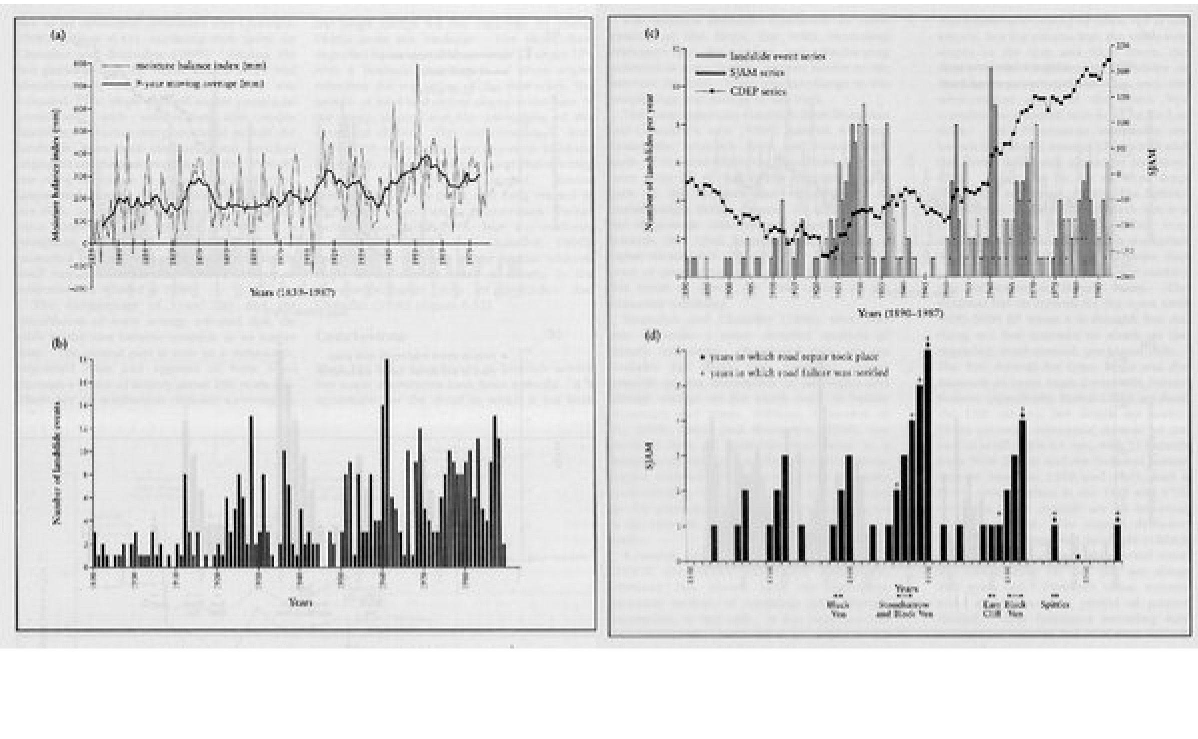
(Figure 6.47) Cliff recession at Black Ven between 1958–1988. After Chandler and Brunsden (1995).



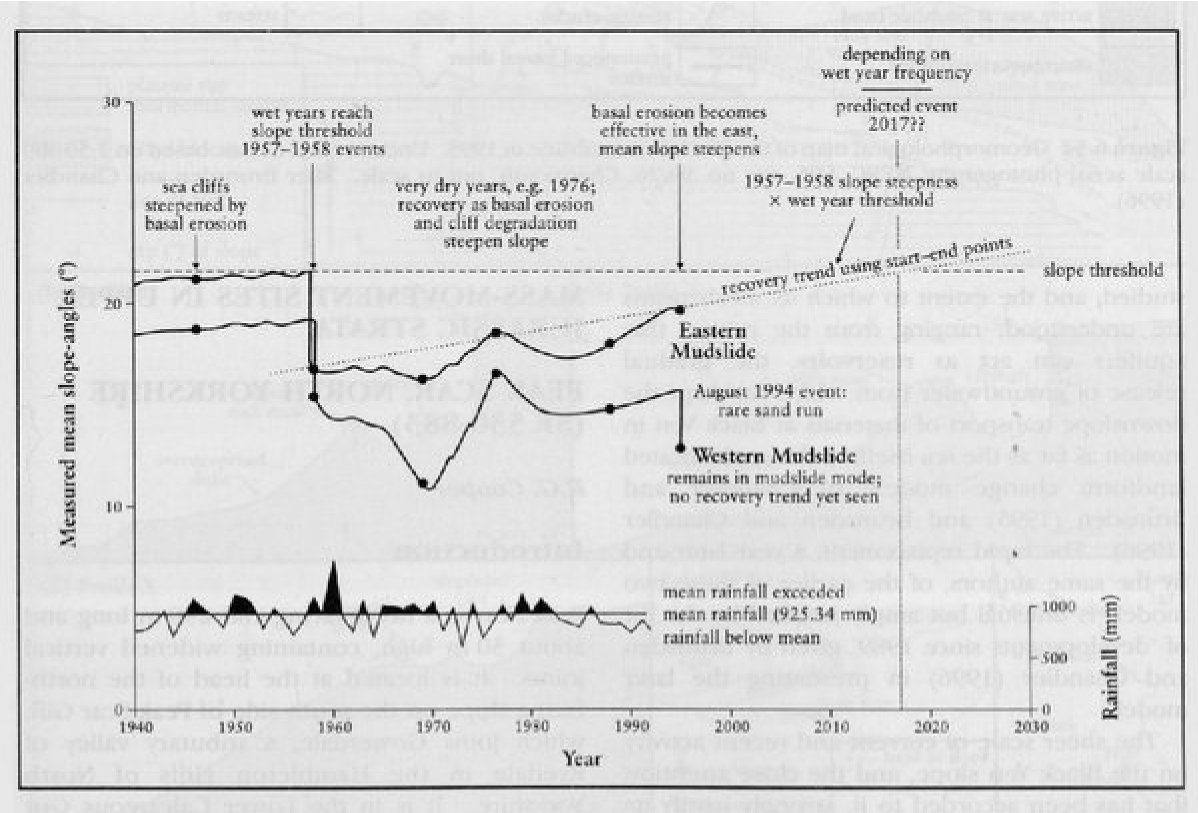
(Figure 6.48) Linear model of landslide activity at Black Ven. The lowest diagram is a speculative cyclic model. After Chandler and Brunsden (1995).



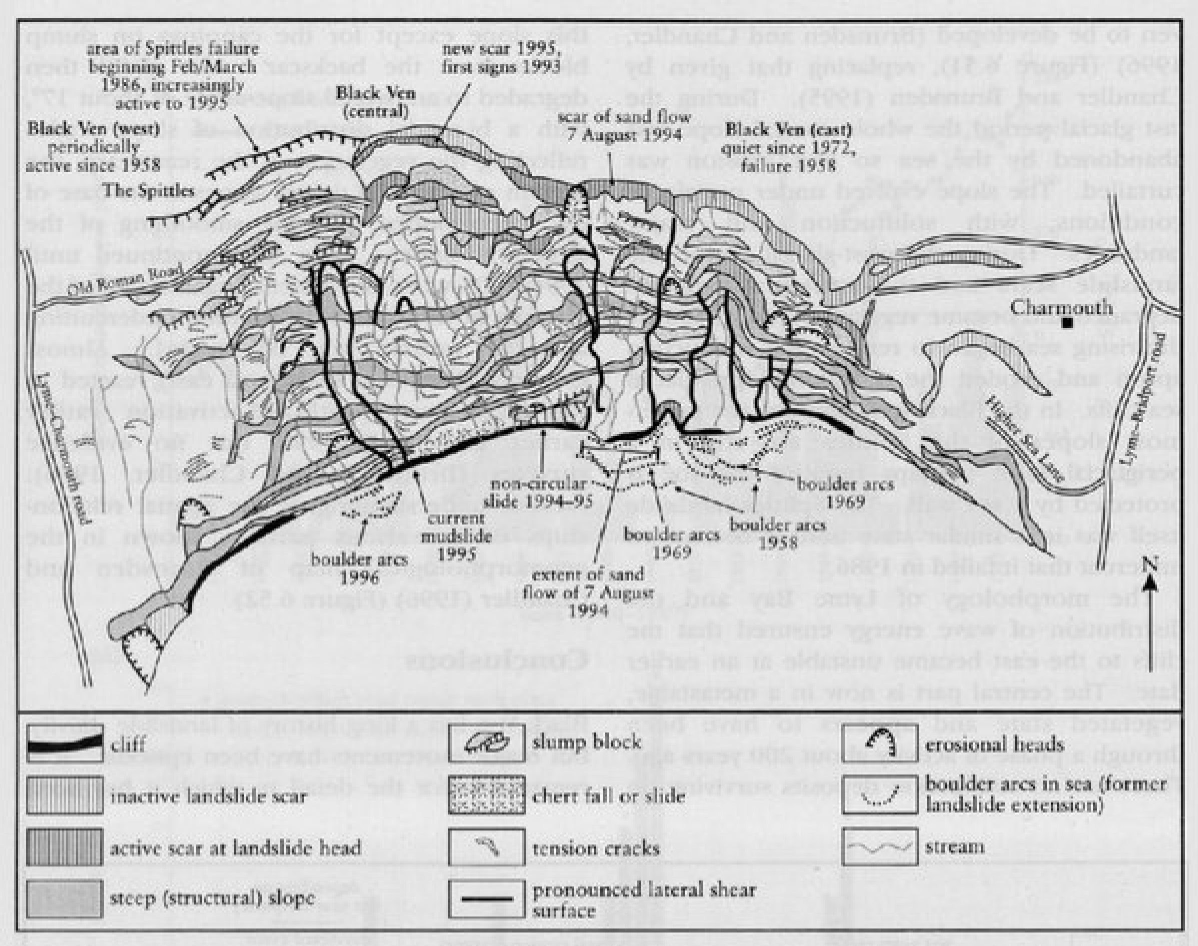
(Figure 6.49) Slope-angle graphs for (a) the east system and (b) the west system of Black Ven. After Brunsden and Chandler (1996).



(Figure 6.50) Climate and landslide series for the south coast of England. (a) Moisture balance (mm) for Ventnor (Isle of Wight) (1639–1987) plotted as a 9-year moving average. (b) The number of landslide events for the south coast. After Ibsen and Brunsden (1996). — continued. Climate and landslide series for the south coast of England. (c) The cumulative moisture balance departure from the mean (CDEP), the cumulative number of years with moisture balance greater than the mean (SJAM) and the landslide occurrence at Ventnor (after Ibsen and Brunsden, 1996). (d) The sequence of years of higher rainfall and landslide occurrences for west Dorset (after Brunsden and Chandler, 1996).



(Figure 6.51) A temporal model of episodic landform change at Black Ven. After Brunsden and Chandler (1996).



(Figure 6.52) Geomorphological map of the Black Ven mudslide in 1995. Uncontrolled mosaic based on 1:50 000 scale aerial photographs, NERC 2/95, site no. 94/26, Charmouth, not to scale. After Brunsden and Chandler (1996).